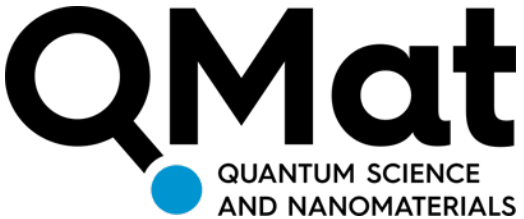
Lucas MARTEL

Masters thesis defense
19/06/2020

Search for $B \to K^{(*)}\nu\bar{\nu}$ decays In the Belle II experiment

Masters internship (Unistra, QMat)
03/03/2020 – 28/07/2020
Tutors : Isabelle Ripp-Baudot, Giulio Dujany

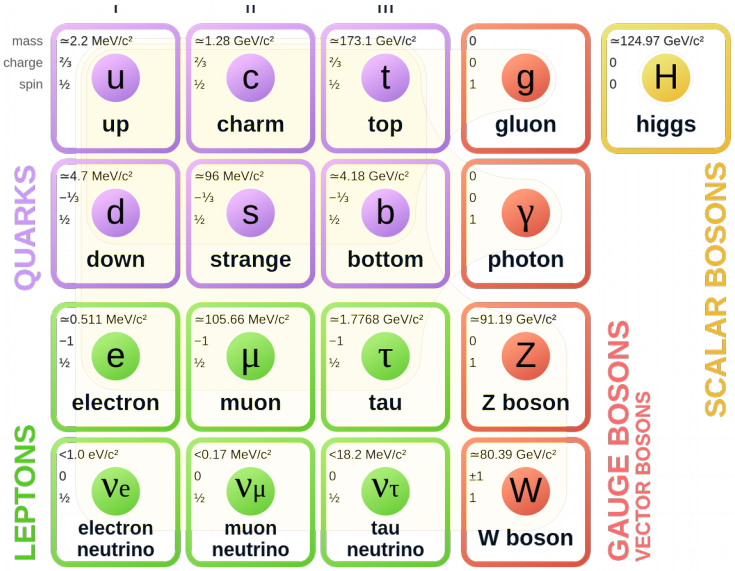


Search for $B \to K^{(*)}\nu\bar{\nu}$ decays In the Belle II experiment

1. **State of the art**
2. the Belle II experiment
3. Analysis
4. Results

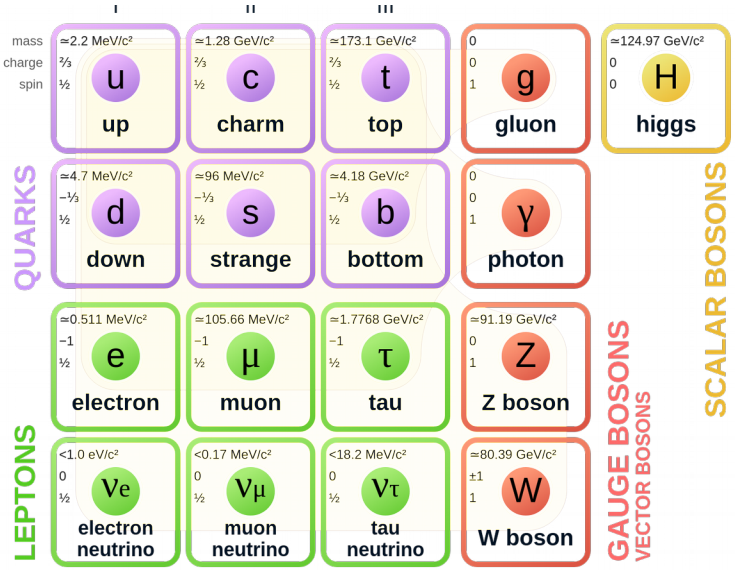
The Standard Model and beyond

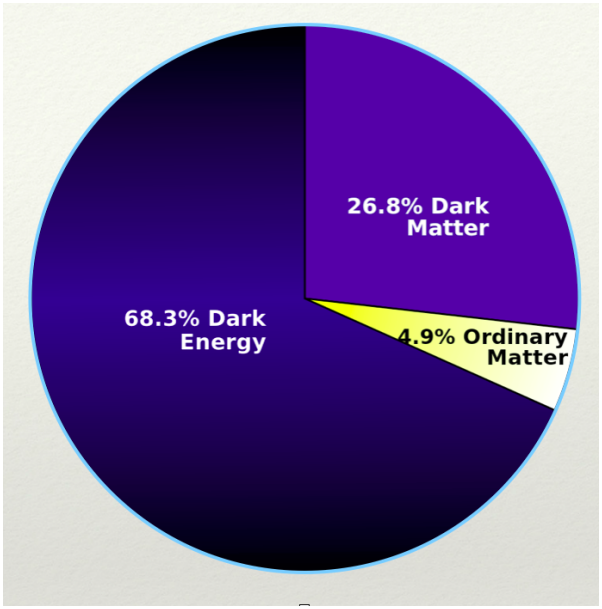
Standard Model



The Standard Model and beyond

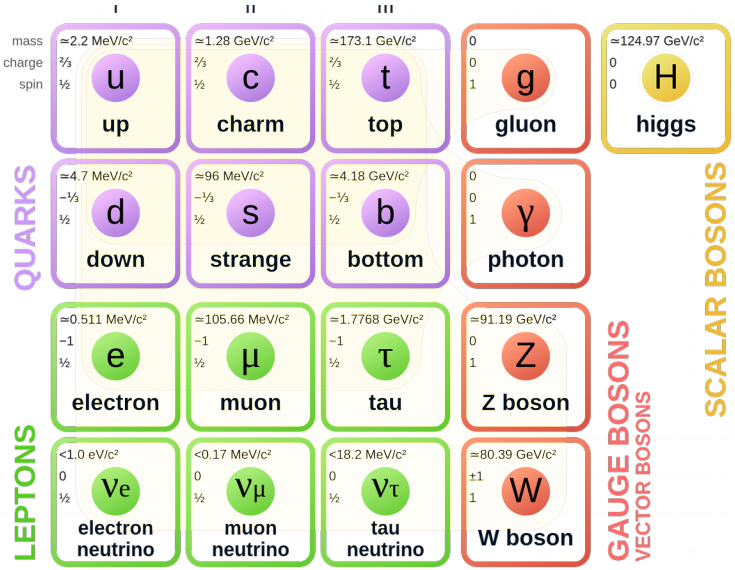
Standard Model → Disagreements

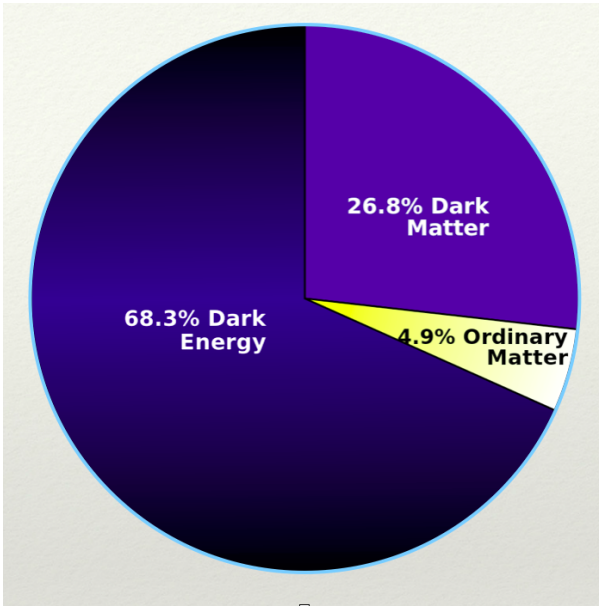




The Standard Model and beyond

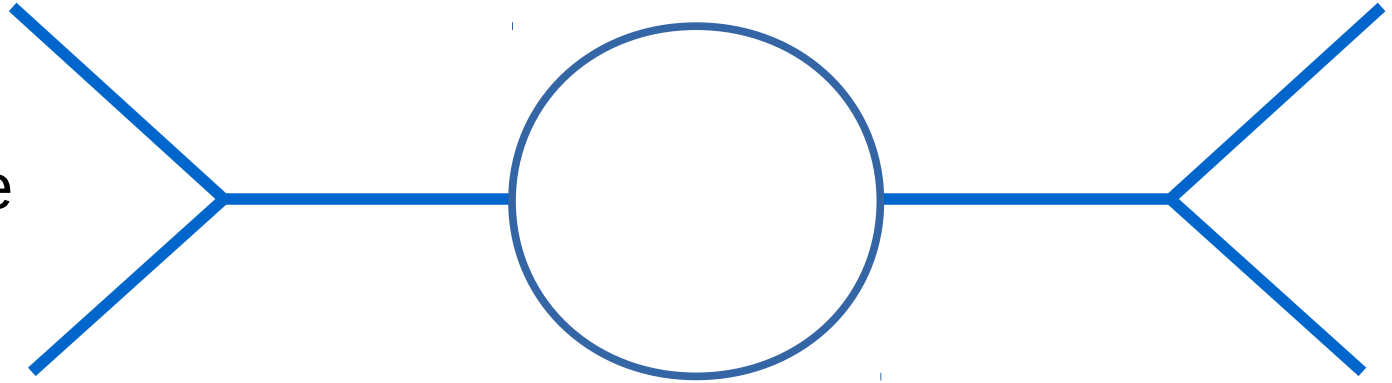
Standard Model → Disagreements → New Physics





Search for New Physics

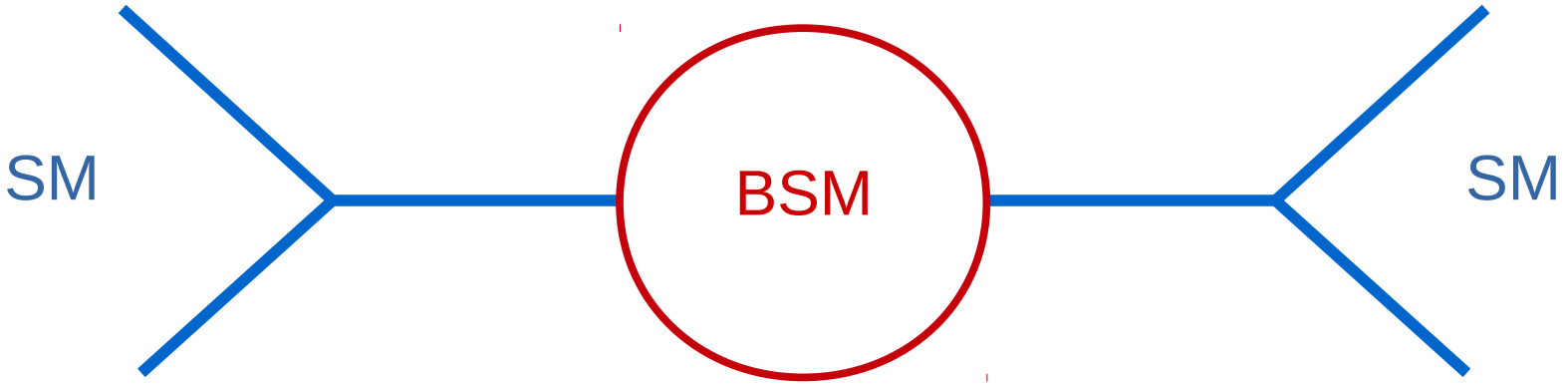
Quantic way



Standard Model probability

Search for New Physics

Quantic way



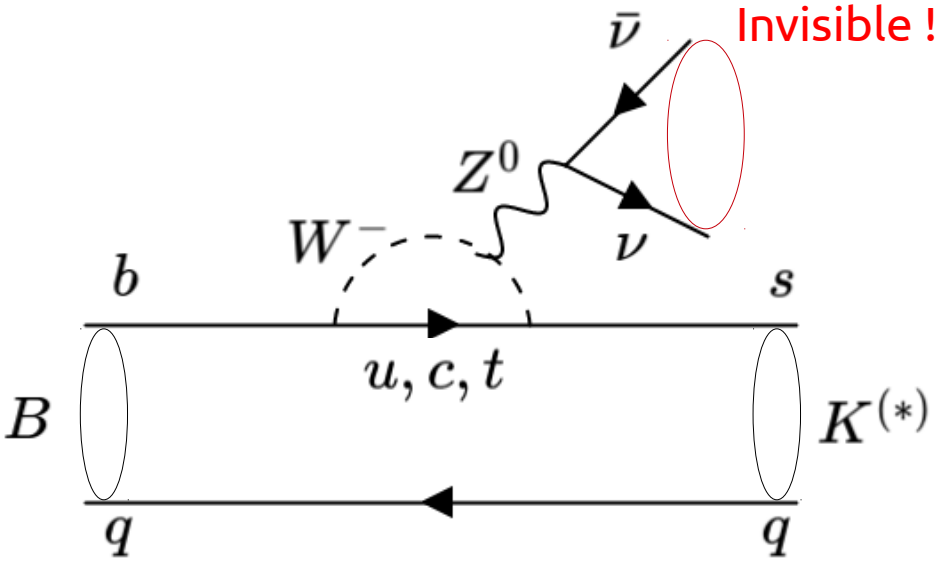
Skewed probability

Needs **high precision : Belle II experiment**

New Physics in $B \to K^{(*)}\nu\bar{\nu}$

$B \to K^{(*)}\nu\bar{\nu}$ decay :

- Never discovered
- Partially invisible final state
- Probability : $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu}) \sim 10^{-6}$



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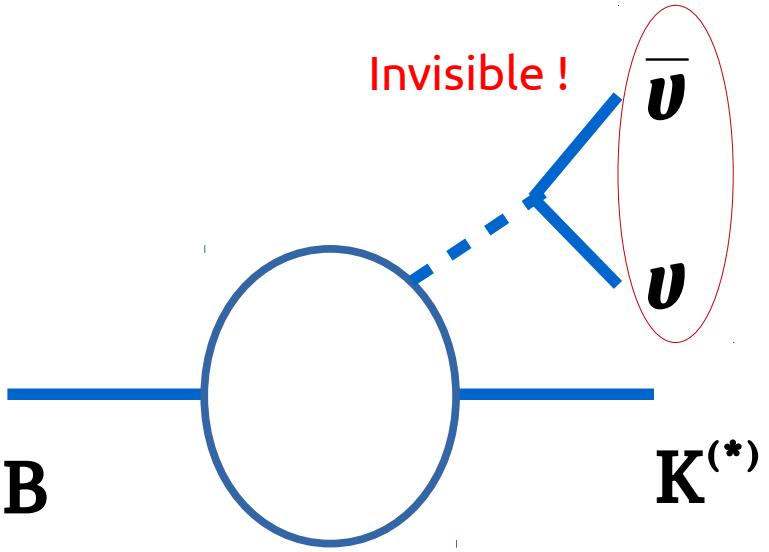

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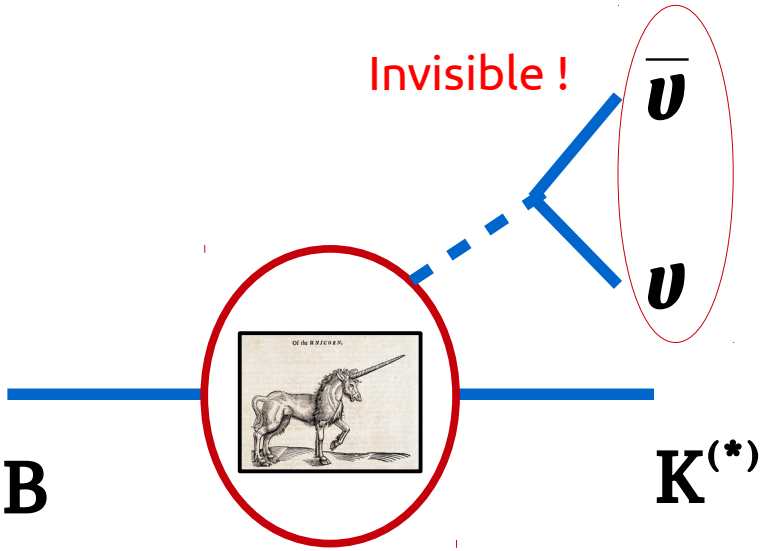

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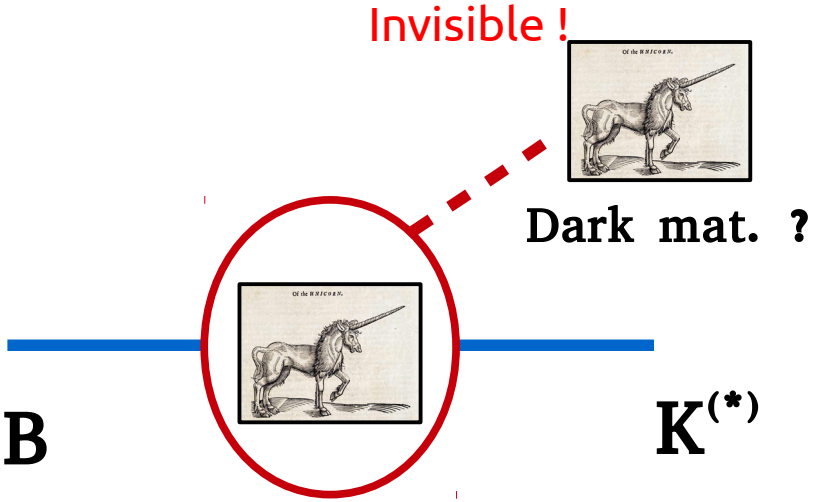

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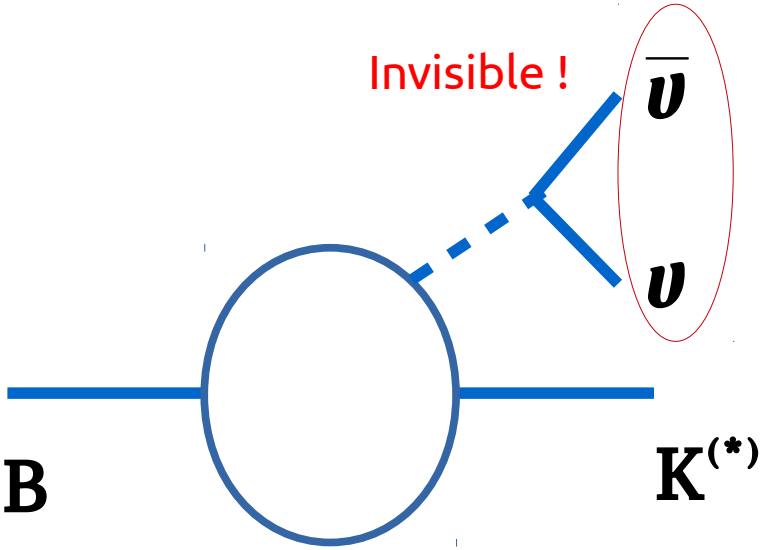

$B \to K^{(*)}\nu\bar{\nu}$ decay :

- Never discovered
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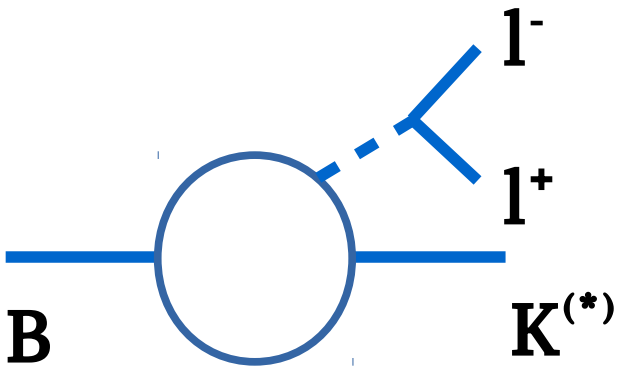
- Probability : $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu}) \sim 10^{-6}$

Similar to $B \to K^{(*)}l^+l^-$:

- Discrepancies already observed
  [F.Archilli et al. Nature, 2017]

  → **inconclusive**



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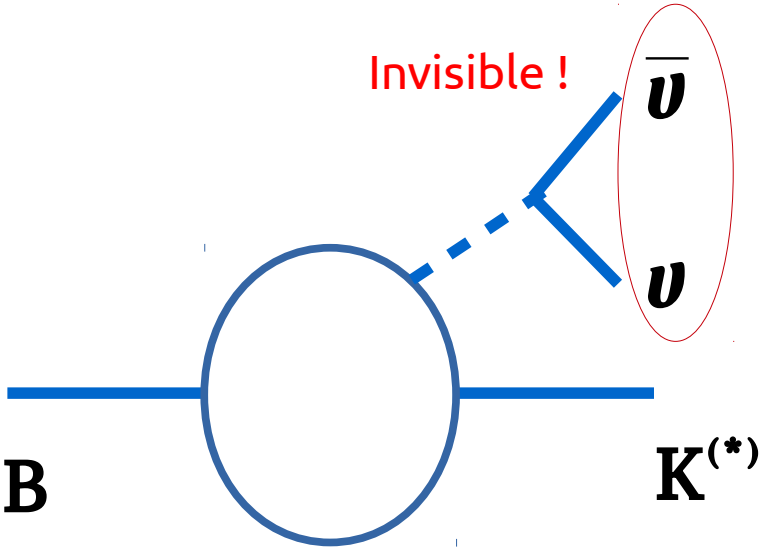

Only in **Belle II !**

Search for $B \to K^{(*)}\nu\bar{\nu}$ decays In the Belle II experiment

1. State of the art
2. **The Belle II experiment**
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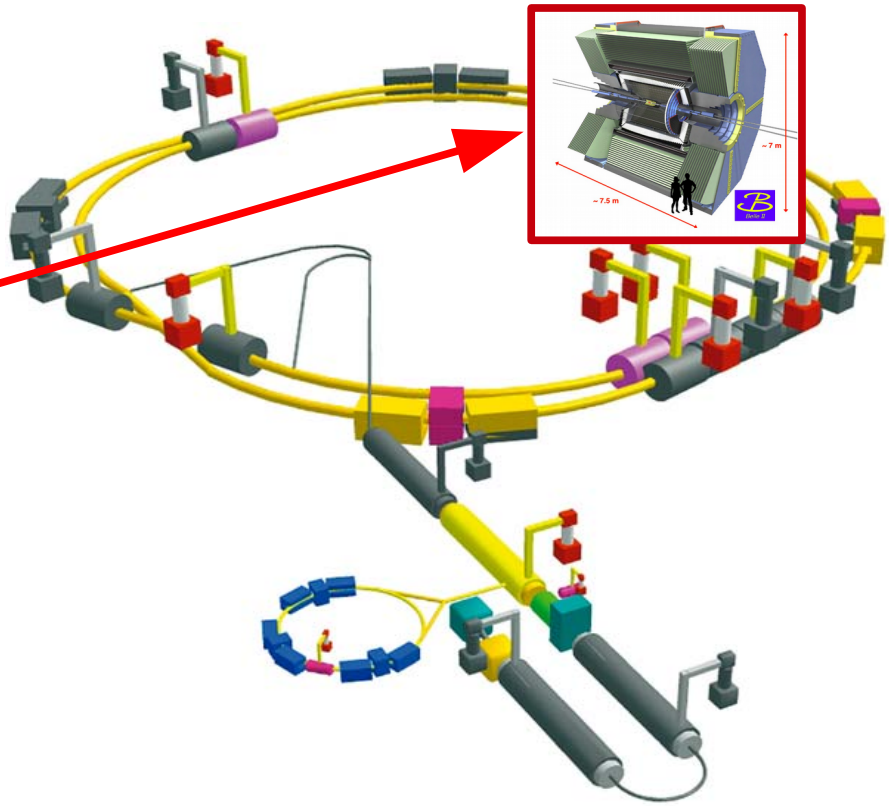
The Belle II experiment

- International collaboration – 2019
- e^+e^- collider 7 GeV vs 4 GeV
- Instantaneous **Luminosity** highest in the world (8×10^{35} $cm^{-2}s^{-1}$)

  → **Statistics = Precision**

The Belle II detector :

- Improvements since Belle detector (1998 -2010)



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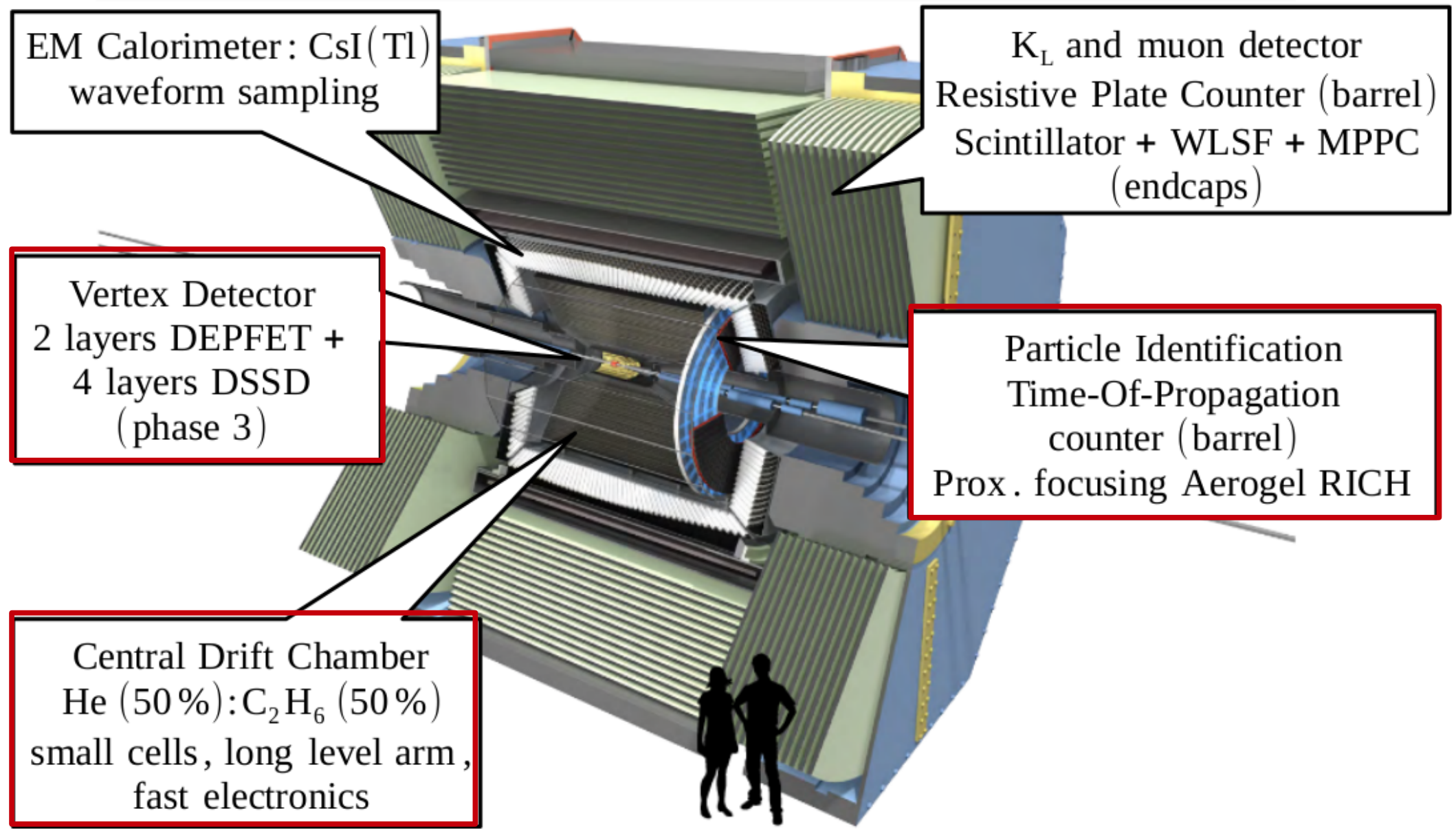
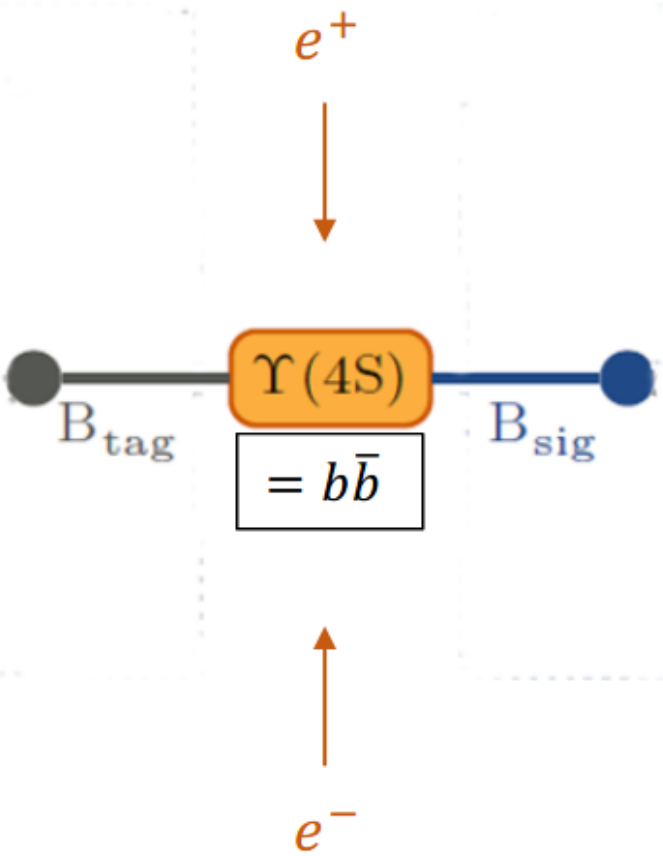


Collisions in Belle II

e^+ e^- collisions
→ Production of a B meson **pair**



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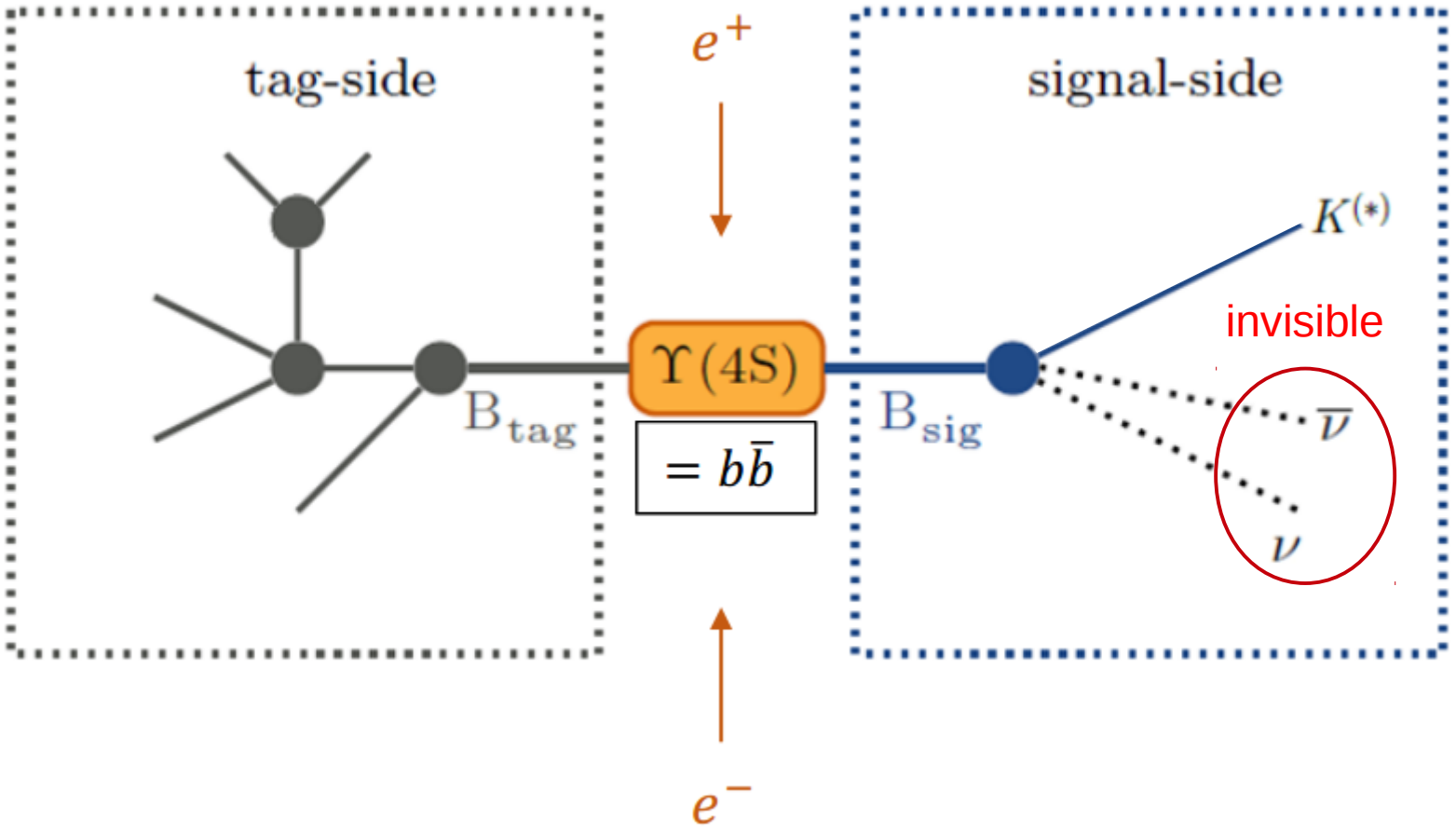

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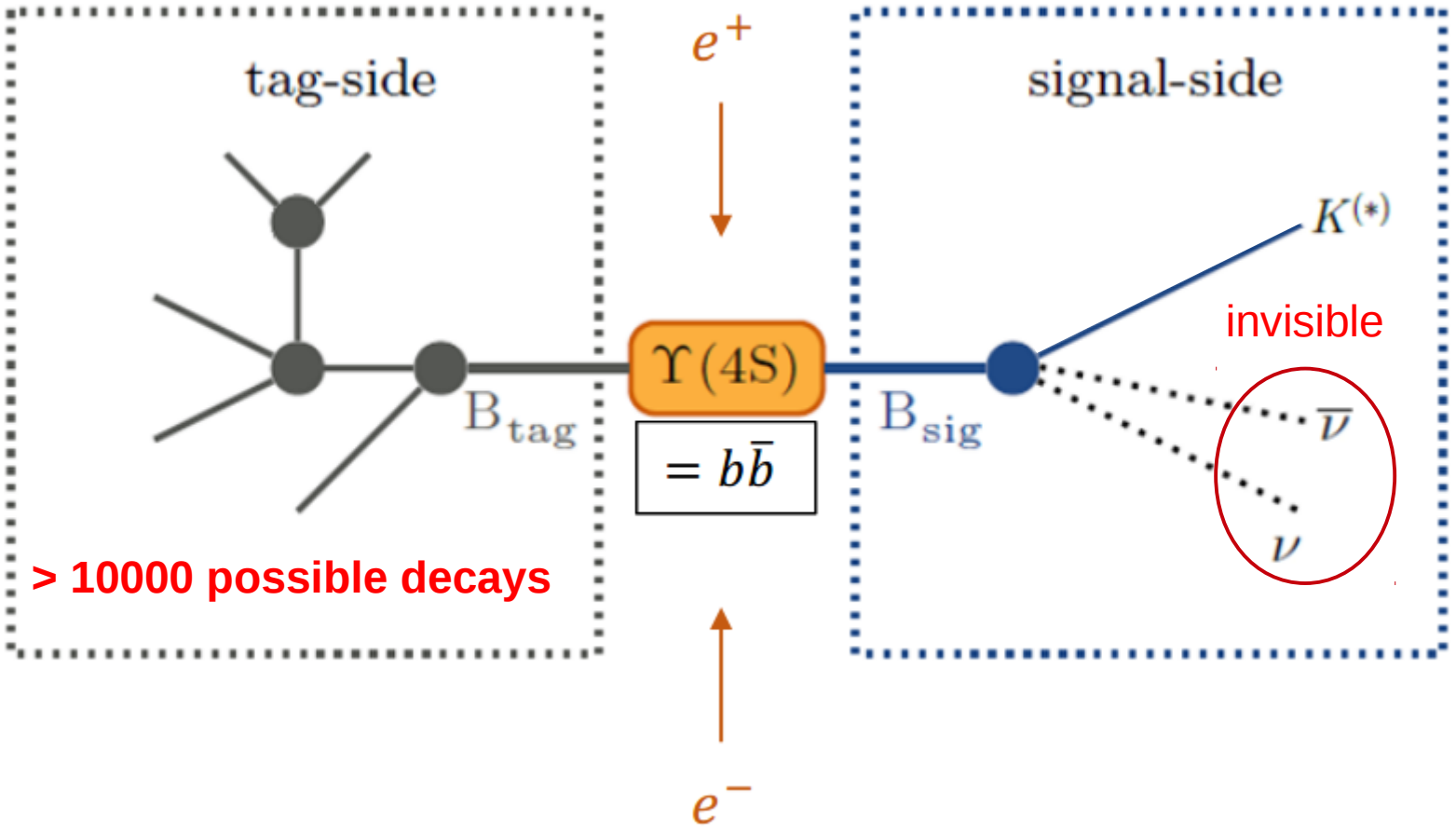

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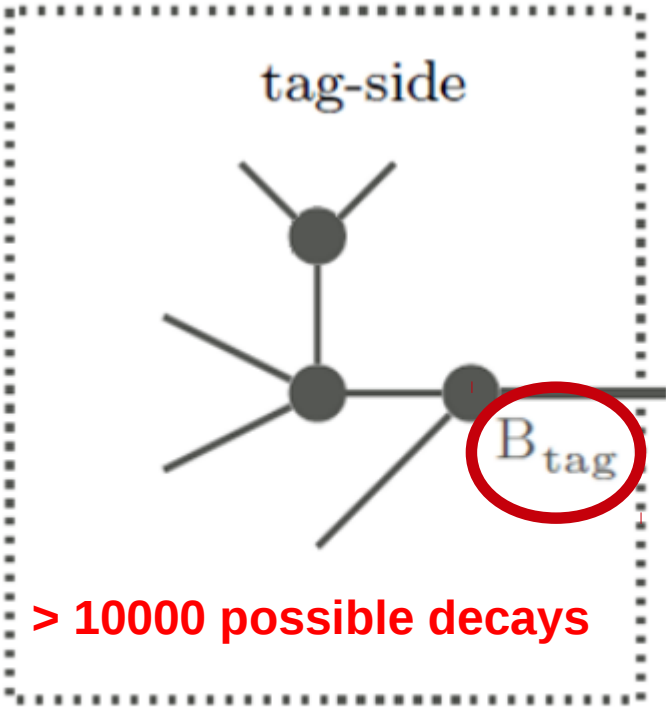
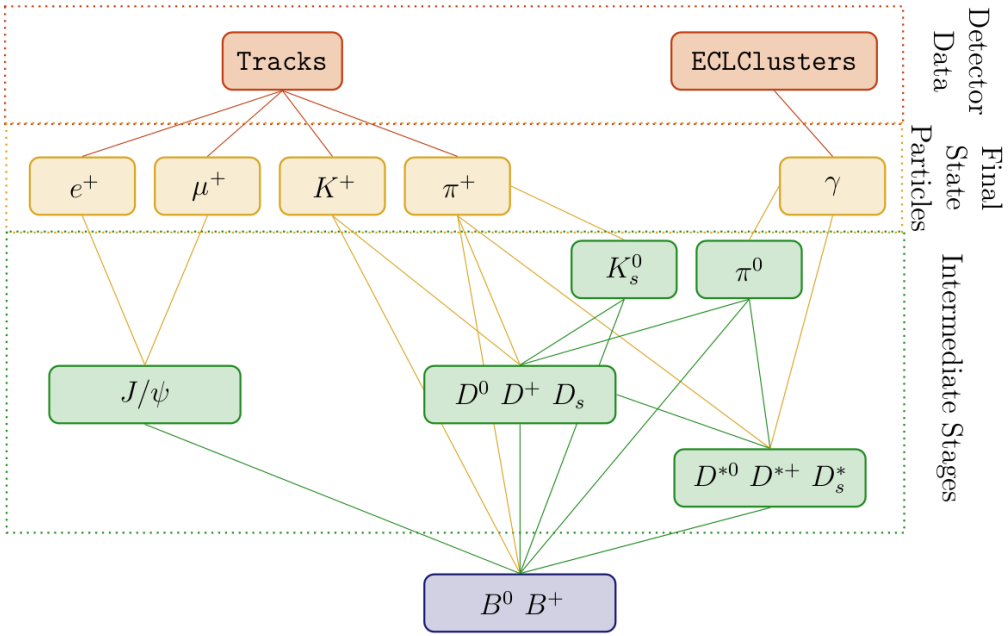
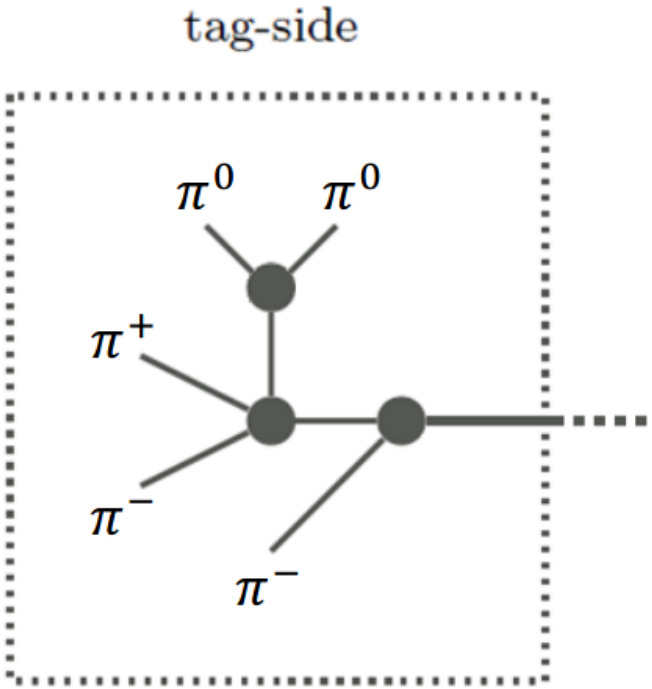


Importance of the
Btag reconstruction

Full Event Interpretation (FEI) algorithm

- How to observe invisible signal ?
  → Btag reconstruction
  → Full Event Interpretation (FEI) : tag side reconstruction algorithm (*machine learning*)
  [T.Keck et al.Computer Software Big Science 2019]





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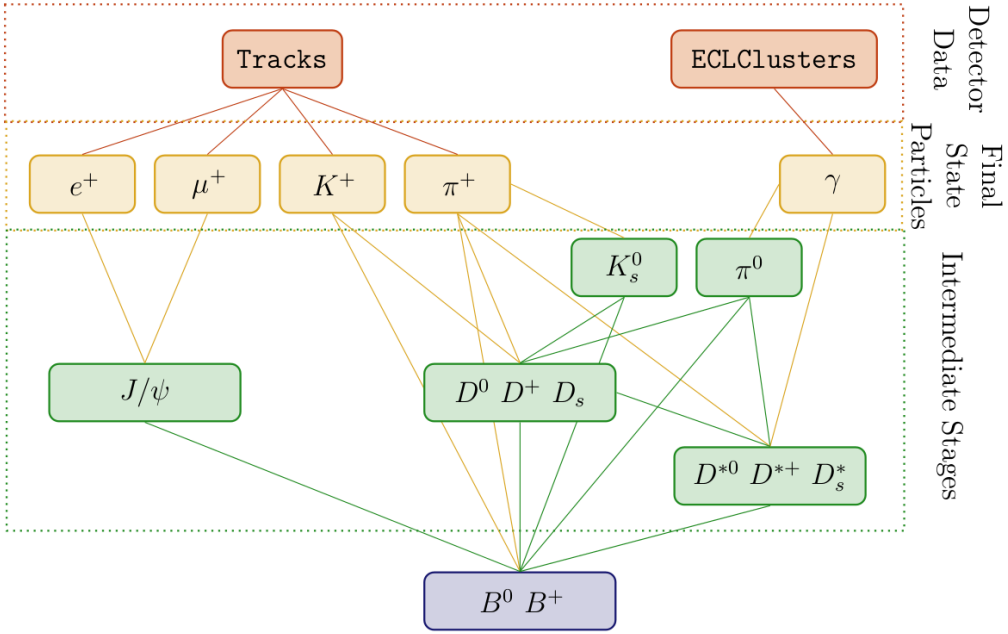

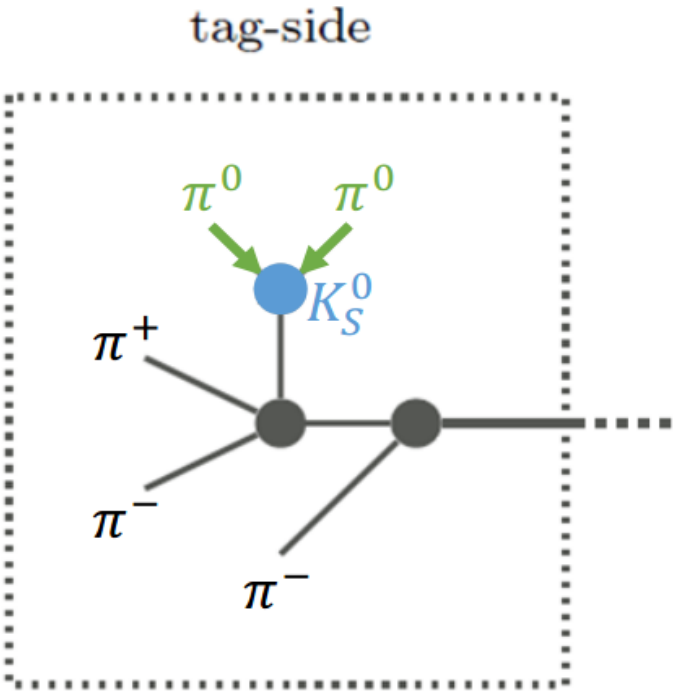

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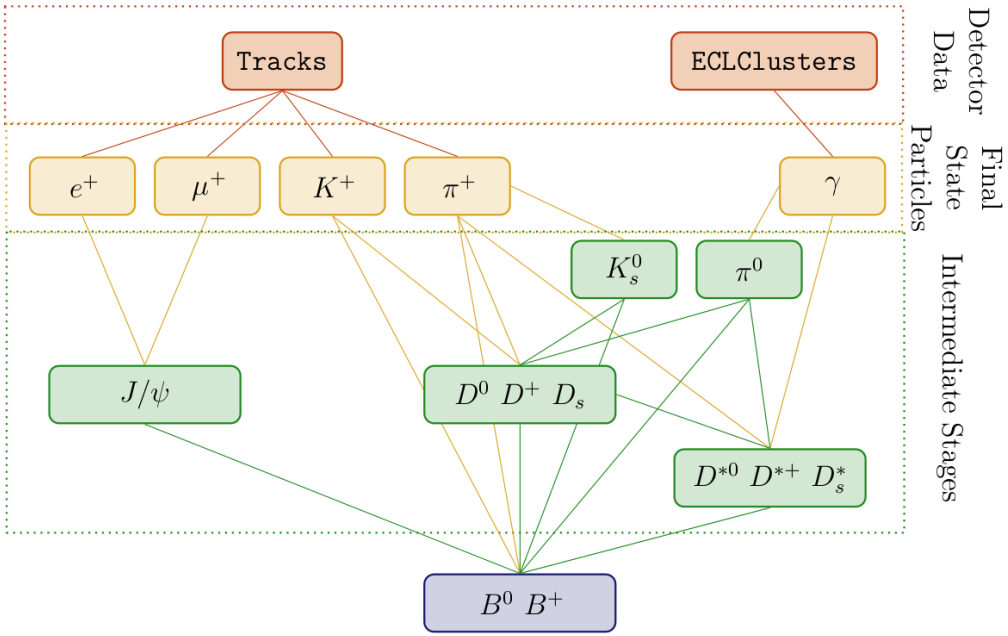

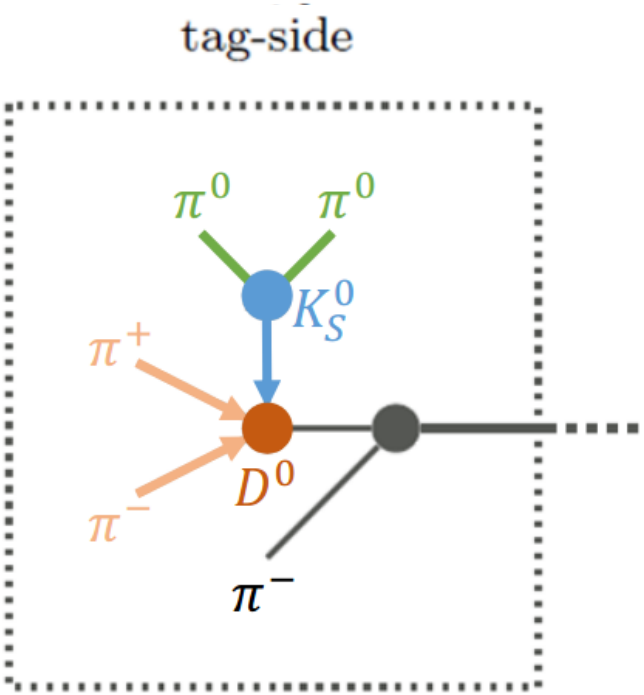

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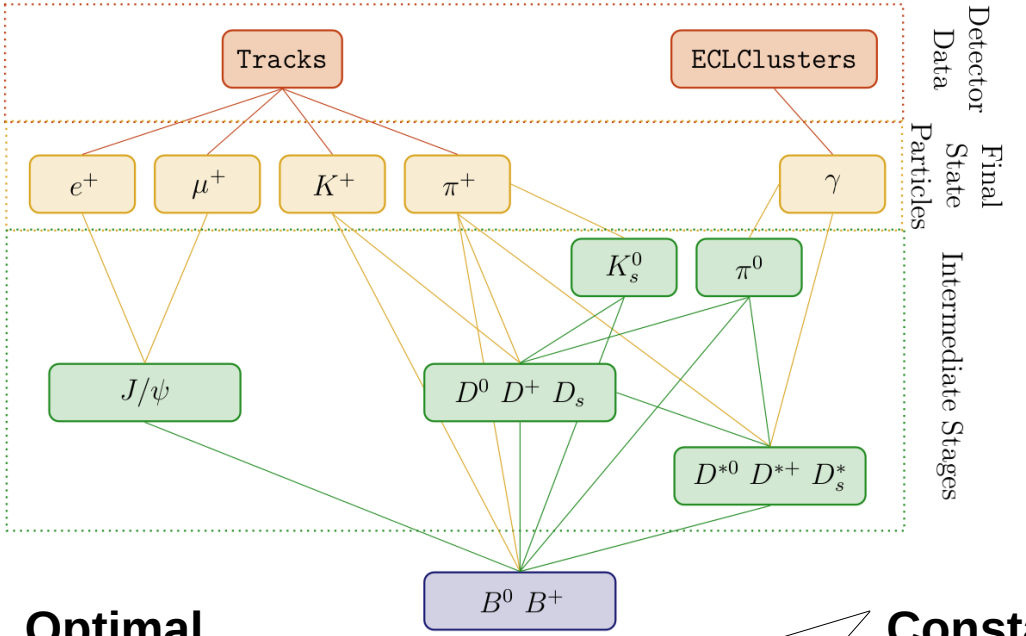

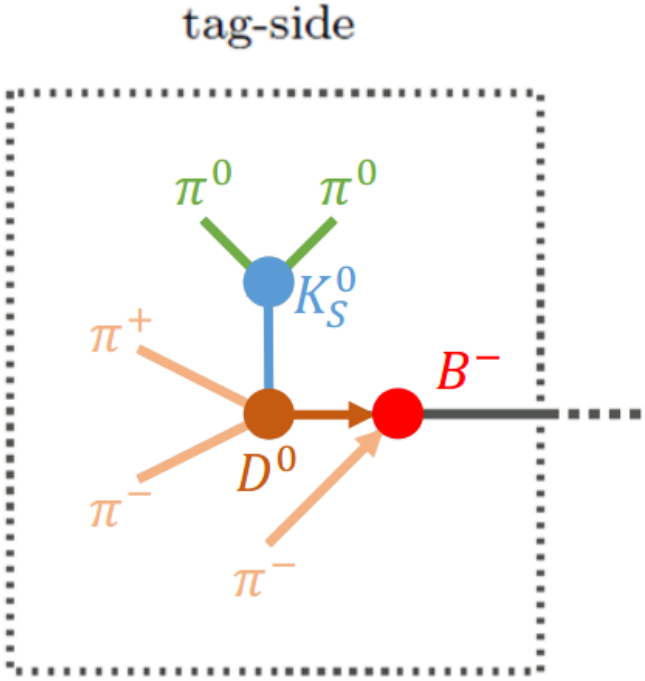

Optimal **Constants**

$$N = L \times \sigma \times \varepsilon \times \mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$$

N = number of signal events

ε = efficiency

Full Event Interpretation (FEI) algorithm

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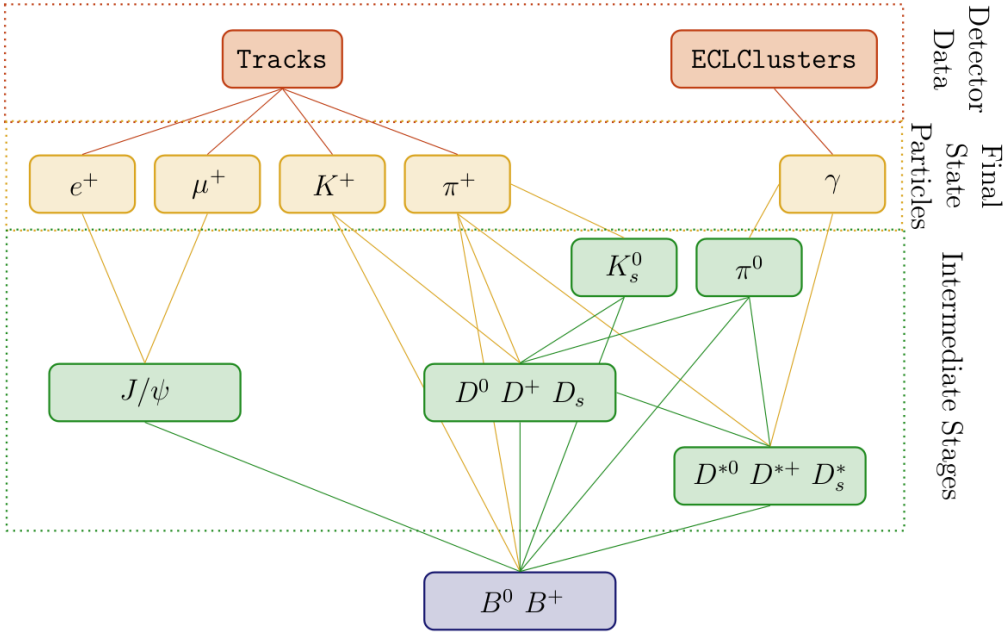

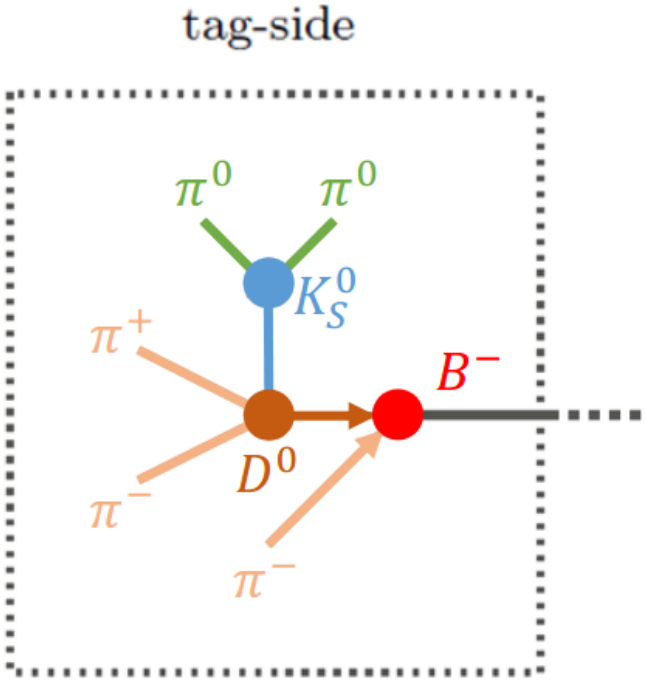

N = Constant X ε

ε = efficiency

N = number of signal events

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Internship goal

$$N = L \times \sigma \times \varepsilon \times \mathcal{B}(B \to K^{(*)} \nu\bar{\nu})$$

- Search for $B \to K^{(*)} \nu\bar{\nu}$ in Belle until 2010 → statistics too low
  [O.Lutz et Al. Physical Review D 2013]
- Simulation in Belle II in 2019 in Strasbourg → ε too low
- Since 2019 : corrections and enhancements to the simulation

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My work :

Quantify these enhancements and find new ways to improve **ε**

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My work :
Quantify these enhancements and find new ways to improve **ε**

$\varepsilon \approx \varepsilon_{signal} \times \varepsilon_{tag}$ → We want to maximize ε_{tag} to optimize the FEI **Learning**

How to measure ε_{tag} ?

Use of $B^0 \rightarrow \nu\bar{\nu}$ as a tool :

Invisible final state → $\varepsilon = \varepsilon_{tag}$

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Use of $B^0 \rightarrow \nu\bar{\nu}$ as a tool :

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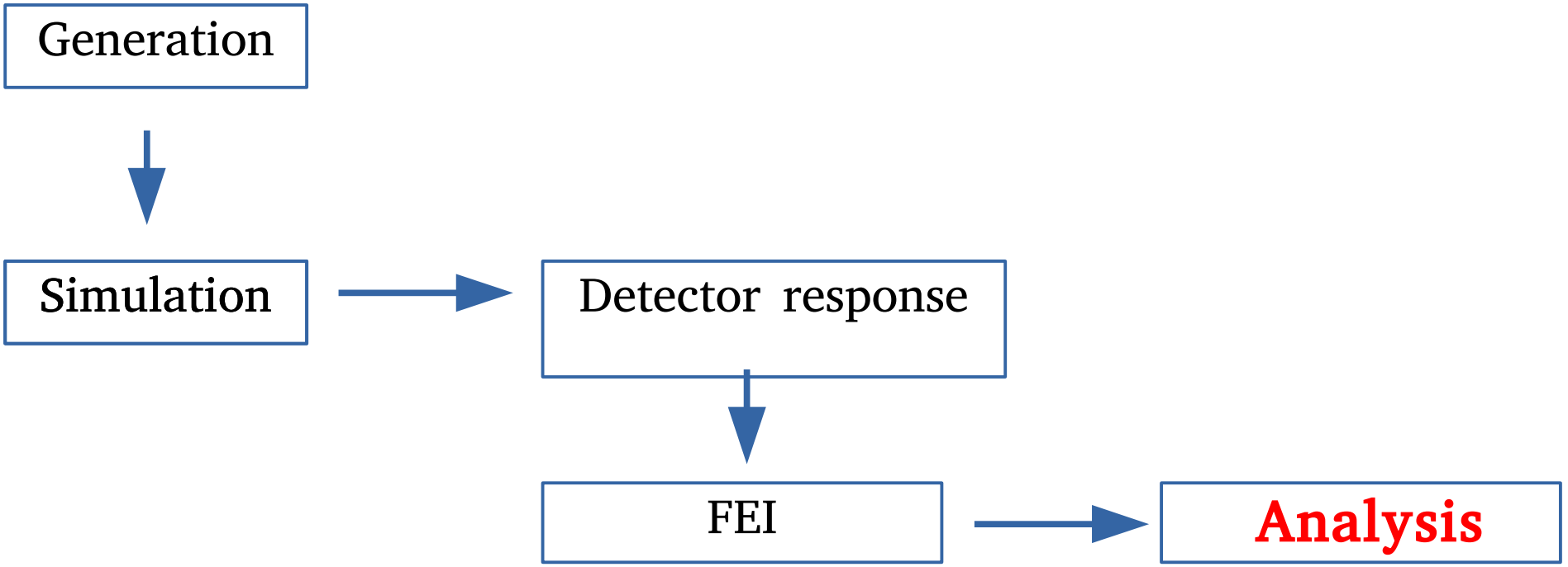
We simulate B meson pairs with one B decaying in $B^0 \rightarrow \nu\bar{\nu}$ (signal) and the other decaying generically (tag)

- Study done on Monte Carlo **simulations**
- Comparison between 3 simulations :

  Belle II → 'B2_2020', 'B2_2019'
  Belle → 'Belle'

Analysis



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Measured performances

	Belle	B2_2019	B2_2020
% of reconstructed Btag decay chains	4,0 ±0,2 %	4,3 ±0,3 %	**10,0 ±0,4 %**
Efficiency on FEI **known** chains	**$(1{,}87 \pm 0{,}01)10^{-2}$**	$(0{,}71 \pm 0{,}01)10^{-2}$	**$(2{,}43 \pm 0{,}02)10^{-2}$**
ε_{tag}	$(0{,}54 \pm 0{,}01)10^{-3}$	$(0{,}52 \pm 0{,}01)10^{-3}$	**$(1{,}78 \pm 0{,}01)10^{-3}$**

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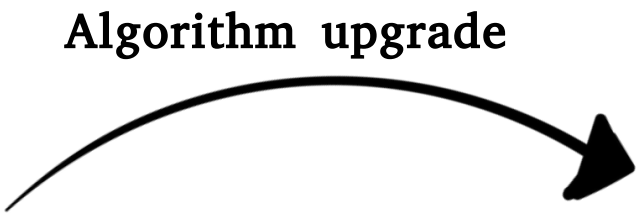
ε_{tag}	$(0{,}54 \pm 0{,}01)10^{-3}$	$(0{,}52 \pm 0{,}01)10^{-3}$	**$(1{,}78 \pm 0{,}01)10^{-3}$**

Measured performances



	Belle	B2_2019	B2_2020
% of reconstructed Btag decay chains	☹	☹	☺
Efficiency on FEI **known** chains	☺	☹	☺
ε_{tag}	☹	☹	☺

X 2,5

X 3

Measured performances

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% of reconstructed Btag decay chains	☹	☹	☺
Efficiency on FEI **known** chains	☺	☹	☺
ε_{tag}	☹	☹	☺

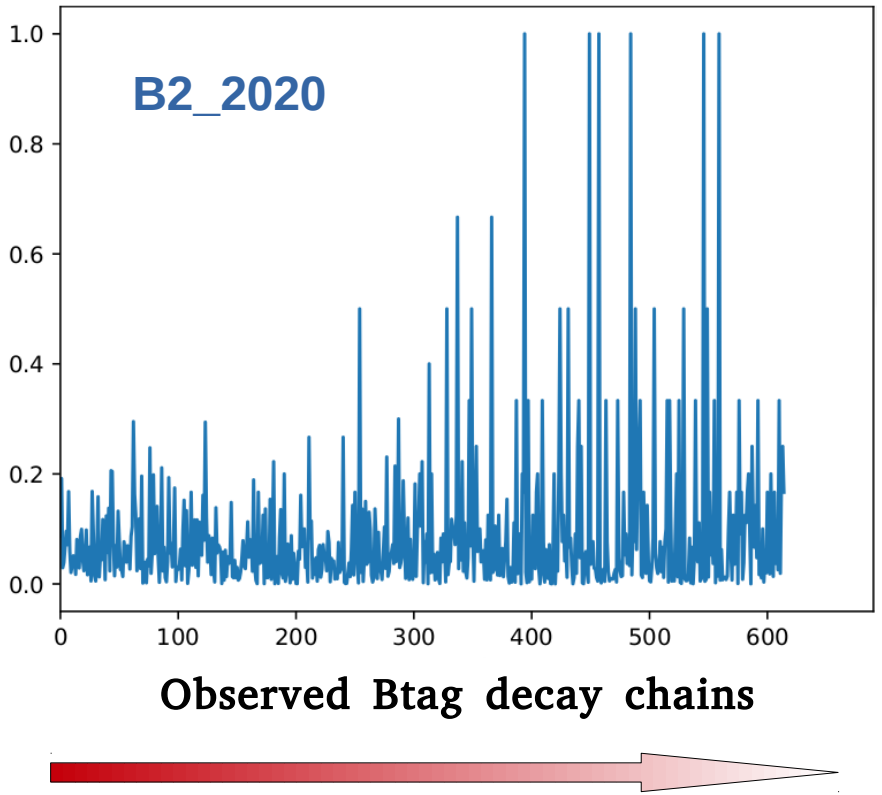
→ X 2,5

→ X 3

- High impact from **2019** upgrades
- Still needs $\boldsymbol{\varepsilon_{tag} \sim x3}$ to discover $B \to K^{(*)}\nu\bar{\nu}$ within **3 years**

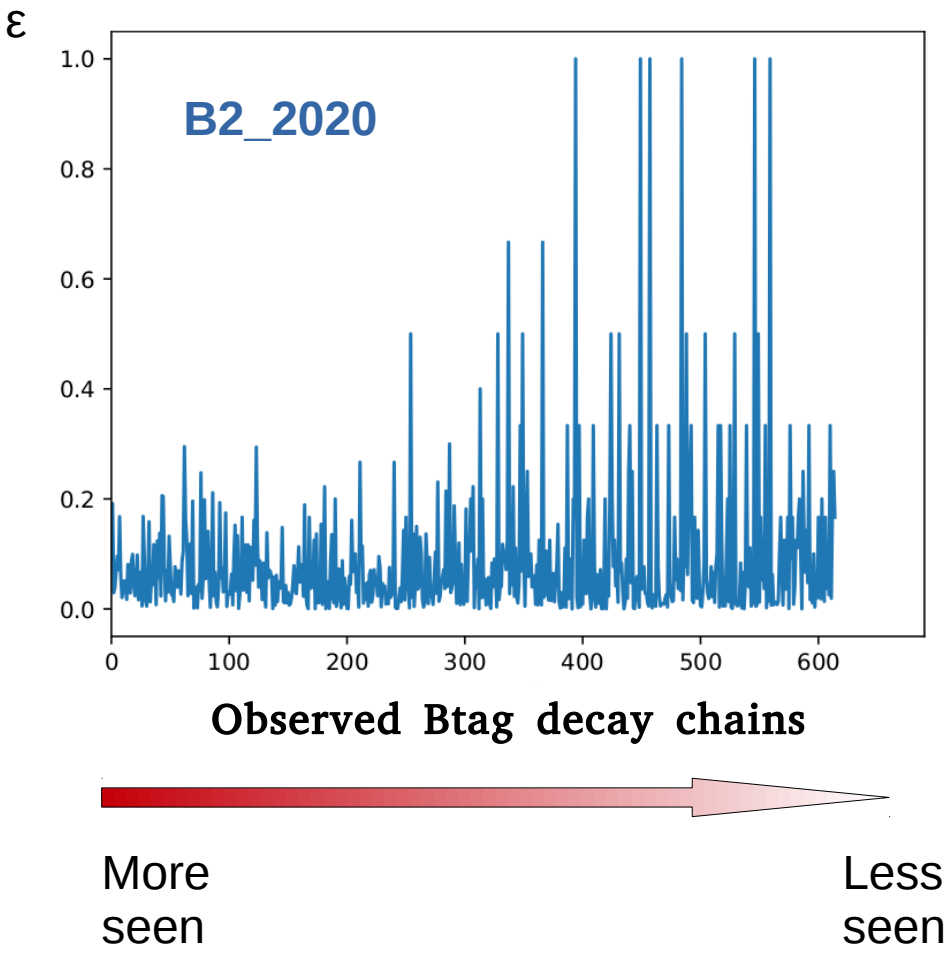
Efficiency by Btag decay chain

ε



- Study done for the first time in the collaboration
- Efficiency different for each chain

Efficiency by Btag decay chain



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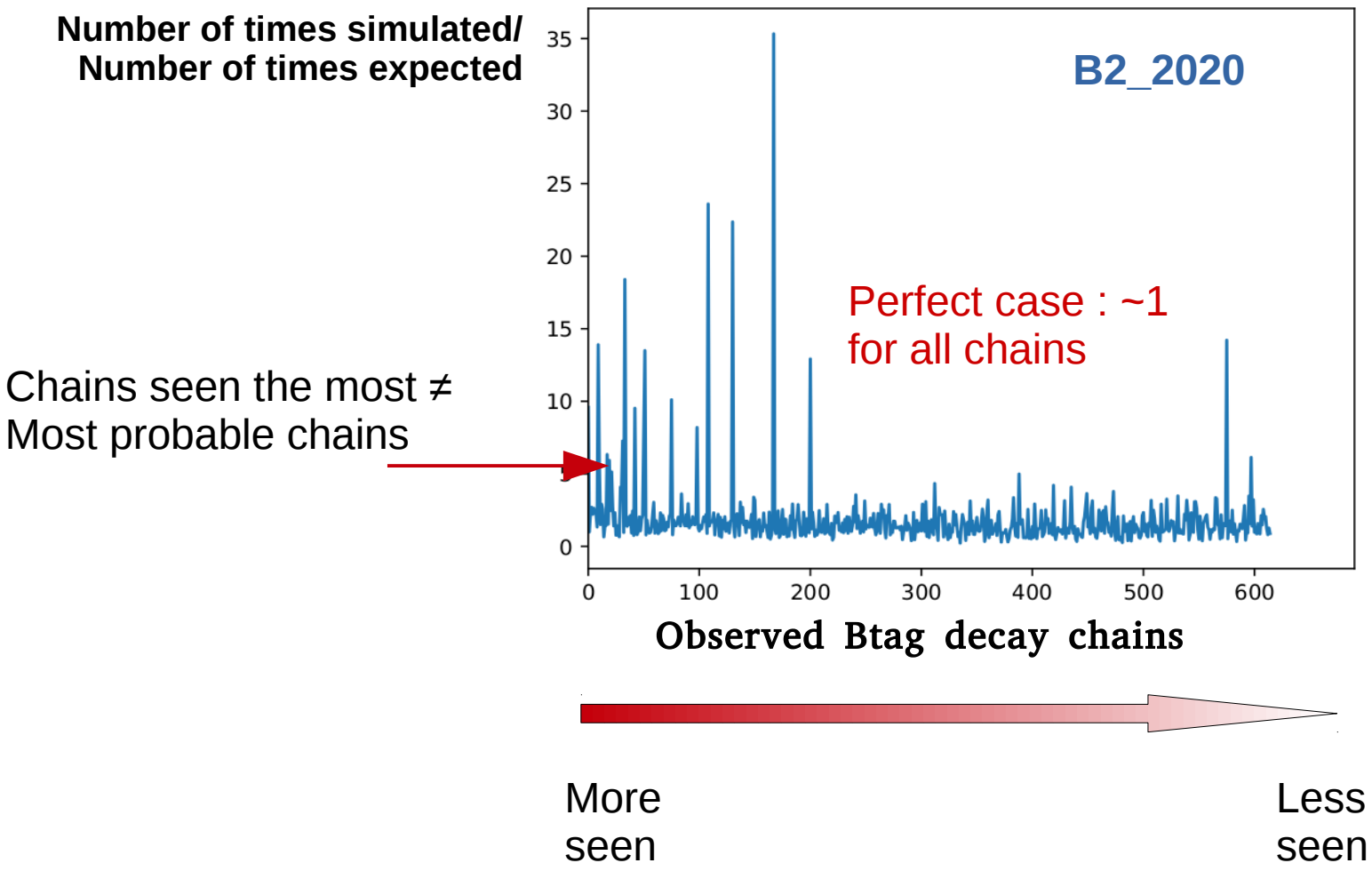
Interesting to understand and optimize the reconstruction

Decay chains simulation discrepancies



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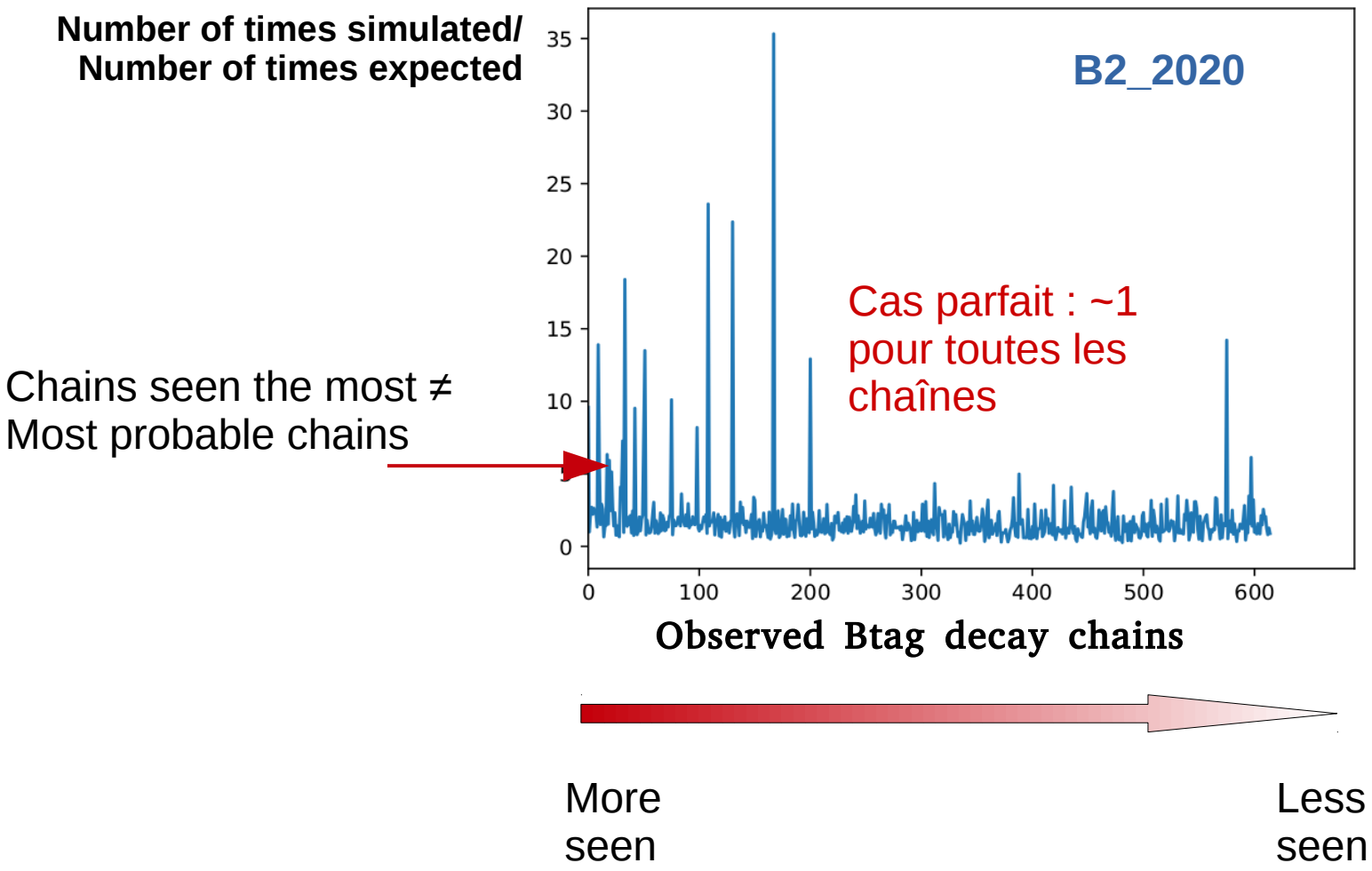

- **Some chains over represented in the simulation**
- **Presented to the collaboration → is going to be corrected**

Summary

From my results :

- Assessment of upgrades → **measurement of** ε_{for} B2_2020
- Search for ways of optimization → First **study** by chains
- Upgrade → **discovery** of the simulation bias

To do next :

- Convolute these results to the signal reconstruction of $B \to K^{(*)}\nu\bar{\nu}$
- Implement new ways to improve efficiency

Thank you for your attention !

Bibliography

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[3] O. Lutz et al.,
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